Conclusions

Increased photosynthetic light received in reflection from the white and aluminum surfaces did not result in longer fibers.

The same elevated FR/R ratio that acts through the phytochrome system to influence cell length and thickness in developing stems can also influence length of a developing cotton fiber, which is an elongated cell.

The phytochrome system is known to influence chemical composition of developing plant stems, and it is hypothesized that cotton fiber chemistry can also be influenced by the FR/R ratio received during fiber development.

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Table 1. Cotton seedling stem elongation responses to red (low FR/R ratio), far-red (high FR/R ratio) and FR followed immediately by R to test photoreversible control as evidence of phytochrome involvement.

	End-of-day FR/R ratio		
	Low	High	High, Low
Hypocotyl (in)	2.47 a	4.80 b	2.53 a

Seedling hypocotyls were measured 10 days after emergence.

Table 2. Approximate reflected FR/R ratios and mean lengths of cotton fiber grown on plants in full summer sunlight over different colored surfaces.

	Color of reflector on soil surface			
	Green	Red	White	Aluminum
FR/R ratio*	1.3	1.2	1.0	1.0
Fiber length (in)†	1.46	1.38	1.21	1.26

* In upwardly reflected light. All plants received full incoming sunlight.
† Measurements were from seed to tip of longest fibers. There were 3 such measurements on each of 100 seeds per each of 3 reps per color. Fiber length data are means for 900 measurements.

Table 3. AFIS-derived characteristics of cotton fiber that developed in field plots over red versus aluminum soil covers.

	Color of reflector on soil surface		
AFIS parameter	Red (high FR/R)	Aluminum (low FR/R)	Signif. (P=0.05)
L(w)	1.12	1.05	*
L(w)cv	24.5	26.0	NS
SFC(w)	3.4	4.4	NS
UQL(w)	1.30	1.23	*
L(n)	0.99	0.93	*
L(n)cv	35.5	36.8	NS
SFC(n)	11.9	13.7	NS
UQL(n)	1.24	1.17	*
D(n)	13.3	14.0	NS
D(n)cv	34.1	32.1	NS
Perimeter	50.68	52.31	*

Notes: A(n) values were numerically (but not statistically) higher for fiber grown over white and aluminum (low FR/R) than over either red or green (higher FR/R). Micronafis was also numerically (but not statistically) higher over white than over red or green.

FIBER-QUALITY VARIATIONS RELATED TO COTTON PLANTING DATE AND TEMPERATURE

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Abstract

In 1991 and 1992, four Upland cotton genotypes were planted at two-week intervals from mid-April to mid-May in Florence SC. Harvest dates were similarly staggered so that mean season lengths were 150 d (1991) and 170 d (1992). When fiber characteristics of 'Deltapine 20, 50, 90, and 5690' were quantified by AFIS, mean fiber diameters, perimeters, cross-sections, circularities, and micronaires decreased from earliest to latest planting. Mean fine fiber fractions and immature fiber fractions increased with Julian planting date in all genotypes. The planting-date related variations in cotton fiber quality persisted through yarn spinning and dyeing where environmental effects on fiber maturity increased yarn elongation percent and decreased evenness of dye uptake. Strong relationships were found between fiber quality [maturity] and cumulative heat units (degree-day-16°C) approximately at pre-bloom (50 days post planting) or post-cutout (100 days post planting).

Introduction

Cotton fiber-quality quantitation that improves prediction of the processing performance of a bale of cotton also increases the likelihood that cotton (and textile mills best using such information and predictors) will retain a competitive advantage and full market share. However, quantitations of fiber properties at the individual boll, locule, and seed levels have revealed wide variations in fiber maturity, *i.e.*, circularity, fineness, and micronaire, and identified strong correlations between the variability of fiber maturity and variations in growth environment [Bradow et al., 1996a].

The quantitative effects, over time, of micro-environment on cotton fiber development are more precisely defined at the boll level [Sassenrath-Cole and Hedin, 1996], but environment-induced variability in cotton fiber properties has also been documented in bulk, saw-ginned samples of four commercial genotypes of Upland cotton grown in South Carolina during 1991 and 1992 [Bradow, et al., 1996a]. In addition to documenting the variations in weather (temperature, rainfall, *etc.*) which are associated with any specific growing season, that experimental design also incorporated the environmental variable of staggered planting/harvest dates with growing season lengths constant within crop year.

Growth environment significantly modified fiber properties of all four genotypes, and the effects of those modifications persisted through fiber processing as significant variations in yarn evenness, strength, and tenacity. Environmentally induced variations in fiber properties, specifically those related to maturity, also resulted in modification of dye-uptake capacity [Bradow et al., 1996a, Bradow and Bauer, 1997]. Subsequent efforts toward identifying those environmental factors that induce the most significant modifications in fiber properties have revealed strong correlations between heat accumulation (growing degree days) and fiber maturity [Johnson et al., 1996]. This report describes the relationships between fiber maturity or fineness levels at harvest and cumulative heat units (degree-day-16°C) at pre-bloom (0 to 50 days post planting) or at post-cutout (100 days post planting to harvest).

Materials and Methods

Four commercial Upland cotton (*Gossypium hirsutum L.)* genotypes were used: Deltapine 20 (DP20); Deltapine 50 (DP50); Deltapine Acala 90 (DP90); and Deltapine 5690 (DP5690). The experimental design has been described elsewhere [Bauer and Bradow, 1996]. In brief, the four genotypes were planted in randomized complete block designs with four replicates on Typic Kandiudult soils in Florence, South Carolina in 1991 and 1992. Planting dates, harvest dates, season lengths, total rainfall, and total and periodic heat-unit (DD16 or Degree-Day-16°C) data are shown in Table 1. All fiber was spindle-picked and saw-ginned before analyses of fiber properties and spinning and dye-uptake testing.

Fiber properties were quantified by the AFIS airflow particle-sizer (Advanced Fiber Information System, Zellweger-Uster) [Bradow et al., 1996a; 1996b]. Definitions and abbreviations for AFIS fiber properties are listed in Table 2.

All AFIS fiber property data were subjected to two-way analyses of variance with genotype and environment (crop year + planting date) as the main effects and data pooled over planting date ($n = 12$). Where significant effects of environment on a specific fiber property were found, three-way analyses of variance were used to determine whether the environment-induced modifications in that property were related to crop year, planting date, or the interaction of those two environment components ($n = 4$). Where planting date was found to be a significant environmental factor, linear regression models were constructed for individual fiber properties versus heat-unit (DD16) accumulations at 50, 100, 150 days after planting (DAP) and at harvest.

Discussion

The four genotypes discussed here are from the same genetic cluster and represent a range of relative maturity and geographical areas of commercial production. Genotype was the main determinant of fiber length and diameter, and growth environment or growth environment interactions with genotype modified staple length and Short Fiber Content (Table 3.) Fiber diameter depended on genotype alone.

Environmental effects were more evident when fiber properties related to maturity were examined (Table 4). Fiber maturity, quantified as θ, IFF, micronAFIS or Pc, was determined by genotype, environment, and differential interactions of the individual genotypes with the environment. No significant interactions between genotype and environment were found in the A[n] and FFF data analyses.

Year and planting date components of the environmental effects on fiber maturity were separated by three-way factorial analyses of variance (Table 5). All three main effects, *i.e.*, genotype, planting date, and year, were significant ($p < 0.001$) for θ, IFF, A[n], and micronAFIS. Genotype was significant at the same level for FFF and Pc. The genotype X year interaction was significant ($p < 0.05$) for θ, IFF, and micronAFIS. The planting date X year interaction was significant at the same level for A[n] and FFF. There were no significant interactions between genotype and planting date or among all three main effects. (Due to space limitations or lack of significance with respect to any fiber property, the genotype, genotype X planting date and genotype X planting date X year columns were omitted from the 3-way factorial ANOVA table, Table 5.)

Possible causes of the significant effects of crop year on fiber maturity properties, *i.e.*, theta, IFF, and micronAFIS, were apparent in the environmental data of Table 1. Overall, 1991 was the shorter, drier, hotter crop year. Significant genotype X year interactions in the θ and IFF data reflect differential responses of the four genotypes to environmental conditions in 1991 and 1992. DP20, DP50, and DP5690 θ means were significantly higher in 1991. DP20 IFF in 1991 was 120 times higher than DP20 IFF in 1992. DP90 θ, IFF, A[n], FFF, and micronAFIS were relatively unaffected by the differences in the 1991 and 1992 growth environments. In 1992, however, DP20, DP50, DP5690 *and* DP90 micronaire means were higher. Differences between 1991 and 1992 micronaire means were particularly pronounced in DP20 and DP5690, the latter genotype exceeding the 4.9 upper micronaire limit in 1992.

The bases for significant planting-date effects were less obvious until the total-season DD16 heat-unit accumulation data were considered in 50-day increments (Table 1). Then, the differences in the 1991 and 1992 thermal environments were found to derive mainly from the higher spring temperatures during the first 50 days after planting [DAP] in 1991. Regardless of planting date and year, heat accumulations during the period between 50 and 150 DAP were not significantly different.

When data were pooled across genotype and fiber property (θ, IFF, A[n], FFF, or micronAFIS) were regressed on DD16 accumulations during the entire season, maturation rates based on heat-unit accumulations and those five fiber properties were from 1.3 to 2.9 times higher in 1991, the hotter year, (Table 6). The differences in 1991 and 1992 heat-unit responses were even more pronounced when only the DD16 accumulations during the first 50 days after planting were considered (Table 7). The slopes of the 1991 heat-unit regression equations based on θ, IFF, A[n], FFF, or micronAFIS were 1.6 to 4.0 times greater than the corresponding 1992 slopes.

More difficult to understand were the slope sign reversals of the 50-DAP heat-unit responses, compared to the overall (0 DAP to harvest) responses. (Compare Tables 6 and 7.) The inverse relationships between DD16 heat-unit accumulations and fiber maturity based on θ, IFF, A[n], FFF, or micronAFIS persisted into the period between 50 and 100 DAP (Table 8) when 1991 rates were from 1.3 to 2.9 times greater than the corresponding rates in 1992. The regression slopes for the 100 to 150 DAP period reversed to the directions reported for the overall fiber property *vs.* DD16 equations (Table 9). In the final 50-day period before harvest, 1991 heat-unit response regression slopes were from 1.3 to 3.0 times greater than those for 1992. Over the total crop year and within the 50-day increments, 1991 DD16-based maturation rates based on micronAFIS were 1.3 to 1.6 times higher than the corresponding 1992 rates. The 1991 maturation rates based on A[n] were 2.9 to 4.0 times higher than the 1992 rates. The highest 1991:1992 heat-unit response ratios were found during the 50-DAP period.

The apparent 'negative' effects on fiber maturation rates of higher heat-unit accumulations during the first 50 DAP and the 50 to 100 DAP periods were observed in all four genotypes in both years. However, the genotypes were not equally sensitive to the differences in 1991 and 1992 thermal environments. The higher DD16 accumulations in the 1991 50-DAP and 50 to 100 DAP periods had the least effect on DP20 and DP5690 maturation rates based on IFF (Table 10). Of the four genotypes in this study, DP50 was the most sensitive to the higher temperatures during the first 100 DAP in 1991. Genotype responses to differences in 50-DAP heat-unit accumulations were similar, regardless of the fiber maturity property used in the heat-unit response comparisons.

Planting date and year interactions were significant factors in fiber A[n] means at harvest (Table 5), as were the effects of DD16 heat-unit accumulations (Table 6). The differences in 1991 and 1992 cumulative DD16 levels altered fiber maturation rates based on A[n] data for all four genotypes (Table 11). The differences between the 1991 and 1992 thermal environments had the least effect on DP90 A[n] and the greatest effect on DP5690 A[n], regardless of DAP period.

The 50-DAP and 50 to 100 DAP periods corresponded roughly to the pre-flowering, vegetative and main-bloom stages of development. It was assumed that the higher heat-unit accumulations early in the 1991 growing season would be correlated with greater boll loading and, therefore, higher demands and competition for resources needed for fiber maturation in that year. This assumption is strengthened by the markedly higher yields in 1991 [Bauer and Bradow, 1996]. Regardless of genotype or planting date, 1991 yields averaged 2.4 times those of 1992.

Both genotype and environmental effects on fiber properties persisted through yarn spinning, knitting, and dye-uptake success (Table 12). Genotype alone determined yarn breaking strength and tenacity. Genotype and genotype-specific interactions with the environment had no effect on yarn nep counts or uniformity coefficients of variation (CV%), which were determined by year (environment) alone. Yarn elongation percent modified by genotype, planting date, and year; and planting date was also a significant factor in breaking tenacity. Elongation percent was the yarn property most closely correlated with fiber maturity, and dye uptake success also depended on fiber maturity [Bradow and Bauer, 1997]. Environment (year + planting date), but *not* genotype, was an important factor in the significant Total Color Differences and Chromaticity Differences of the blue-dyed knits. The planting date component of the growth environment and planting date X crop year interactions were significant factors in the Total Color Differences, and the planting date main effect was also significant in the Chromaticity Difference analyses.

The thermal environment, as DD16 heat-units, was not, of course, the sole determinant of fiber maturity; nor were these extrapolations from properties of field-matured fiber the best descriptors of fiber maturation rates. However, the effects of the overall thermal environment on fiber maturation and variability reported here are consistent with those described in another time-line study of cotton fiber maturation [Johnson, et al., 1996; Johnson et al., 1997] in which are described the effects of micro-environment factors, including DD16, on the properties of fiber collected at 21, 28, 35, 42, and 56 days post floral anthesis.

Summary

The bulk fiber properties used in these analyses were quantified after a full season of growth in the field. The identified variations in fiber properties, particularly those properties most closely related to fiber maturity, represent the genetically and environmentally induced variability in cotton fibers harvested from the *same* fields in the *same* crop year. Inclusion of staggered planting dates in the experimental design had the effect of subjecting plants in the same fields, but at different stages of development, to quantified variations in micro-environment, specifically heat-unit accumulations during the first 50 days after planting.

Higher heat-unit accumulations during the first 50 days after planting resulted in increased boll-loading (and yield) and, concomitantly, in higher competition for metabolic resources during fiber maturation. Such competition decreased fiber maturity at harvest and increased variability in those fiber properties related to maturity, *i.e.*, circularity, immature fiber, fraction, cross-sectional area, fine fiber fraction, and micronaire. These effects of environment, including those of the planting-date induced micro-environments, modified fiber maturity; and those variations and modifications in maturity persisted as environmental effects on yarn evenness, elongation percent, and dye-uptake capacity.

Disclaimer

Trade names are necessary for reporting factually on available data. The USDA neither guarantees nor warranties the standard of the product or service, and the use of the name USDA implies no approval of the product or service to the exclusion of others that may be suitable.

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Table 1. Environmental factors modifying DP20, DP50, DP90, and DP5690 fiber properties in 1991/1992 South Carolina planting date study.

Environmental Parameter	Year	
	1991	1992
Planting Dates	4/17 (early)	4/15 (early)
	5/1 (normal)	4/29 (normal)
	5/15 (late)	5/15 (late)
Harvest Dates	9/17	9/28
	9/23	10/19
	10/10	10/30
Season Lengths	155	167
(Days After Planting,	145	174
DAP)	149	170
Total Rainfall	60.0 cm	89.8 cm
Mean Total Heat Units, Degree-Day-16 [DD16]	1588.8	1352.7
DD16 Heat Units	345.8	183.8
Accumulated by 50 DAP	430.6	237.9
	495.3	362.9
DD16 Heat Units	553.1	528.3
Accumulated Between	600.6	595.0
50 and 100 DAP	586.4	598.6
DD16 Heat Units	587.0	640.6
Accumulated Between	431.9	484.5
100 and 150 DAP	350.9	331.9

Table 2. AFIS fiber property definitions and abbreviations.

Fiber Property	Abbreviation	Definition
Length by Weight	L[w]	Staple length by weight
Short Fiber Content by Weight	SFC[w]	% L[w] < 12.7 mm.
Length by Number	L[n]	Staple length by number
Short Fiber Content by Number	SFC[n]	% L[n]< 12.7 mm
Diameter by Number	D[n]	μm
Circularity	θ or Theta	Wall thickening, fiber maturity
Immature Fiber Fraction	IFF	% θ < 0.25.
Cross-sectional Area by Number	A[n]	Fiber cross-section in μm^2.
Fine Fiber Fraction	FFF	% A[n] < 60 μm^2
micronAFIS	micronAFIS	Micronaire analog
Perimeter	Pc	Calculated

Table 3. Effects of genotype and growth environment on cotton fiber length and diameter. (Two-way analyses of variance, Genotype X Year).

Fiber Property	Mean Square and Significance Level		
	Genotype	Year	Genotype X Year
L[w]	3.78 **	ns	2.41 *
SFC[w]	18.11 ****	3.25 *	3.53 **
L[n]	9.49 ****	ns	2.59 *
SFC[n]	26.63 ****	ns	2.99 **
D[n]	53.49 ****	ns	ns

ns = p > 0.1; *, **, ***, **** indicate p < 0.1, 0.05, 0.01, and 0.001 respectively.

Table 4. Effects of genotype and growth environment on cotton fiber circularity, area, and micronaire. (Two-way analyses of variance, Genotype X Year).

Fiber Property	Mean Square and Significance Level		
	Genotype	Year	Genotype X Year
θ	53.11 ****	48.41 ****	3.27 **
IFF	16.30 ****	10.98 ***	2.87 **
A[n]	9.79 ****	11.20 ***	ns
FFF	18.61 ****	3.64 *	ns
micron AFIS	16.13 ****	30.00 ****	2.40 *
Pc	159.06 ****	21.00 ****	2.59 *

ns = p > 0.1; *, **, ***, **** indicate p < 0.1, 0.05, 0.01, and 0.001 respectively.

Table 5. Significant separate and interactive effects of genotype, planting date and crop year on fiber maturity. (Three-way analyses of variance, Genotype X Planting Date X Year).

Fiber Property	Mean Square and Significance Level			
	Plant Date	Year	Genotype X Year	Plant Date X Year
θ	0.003 ****	0.017 ****	0.001 **	ns
IFF	21.69 ****	27.31 ****	7.13 **	ns
A[n]	178.6 ****	295.6 ****	ns	75.3 **
FFF	20.00 ***	13.24 **	ns	10.10 **
micron-AFIS	0.87 ****	2.95 ****	0.24 **	0.19 *
Pc	8.55 **	ns	ns	6.03 *

ns = p > 0.1; *, **, ***, **** indicate p < 0.1, 0.05, 0.01, and 0.001 respectively.

Table 6. Overall fiber maturation rates [across genotypes] based on DD16 heat-unit accumulations in 1991 and 1992.

Fiber Property	Regression slopes [unit/DD16]	
	1991	1992
θ	+0.0004	+0.0002
IFF	-0.0320	-0.0196
A[n]	+0.1092	+0.0383
FFF	-0.0340	-0.0187
micronAFIS	+0.0067	+0.0051

Table 7. Fiber maturation rates [across genotypes] based on DD16 heat-unit accumulations between 0 and 50 DAP in 1991 and 1992.

Fiber Property	Regression slopes [unit/DD16]	
	1991	1992
θ	-0.00010	-0.00004
IFF	+0.0095	+0.0048
A[n]	-0.0352	-0.0088
FFF	+0.0103	+0.0043
micronAFIS	-0.0022	-0.0014

Table 8. Fiber maturation rates [across genotypes] based on DD16 heat-unit accumulations between 50 and 100 DAP in 1991 and 1992.

	Regression slopes [unit/DD16]	
Fiber Property	1991	1992
θ	-0.00010	-0.00004
IFF	+0.0062	+0.0043
A[n]	-0.0238	-0.0082
FFF	+0.0019	+0.0025
micronAFIS	-0.0015	-0.0012

Table 9. Fiber maturation rates [across genotypes] based on DD16 heat-unit accumulations between 100 and 150 DAP in 1991 and 1992.

	Regression slopes [unit/DD16]	
Fiber Property	1991	1992
θ	+0.00010	+0.00004
IFF	-0.0054	-0.0035
A[n]	+0.0202	+0.0068
FFF	-0.0056	-0.0033
micronAFIS	+0.0013	+0.0009

Table 10. Comparison of fiber maturation rates [based on IFF] of four cotton genotypes in 1991 and 1992.

Geno-type	Maturation rate [slope of IFF vs. DD16] Cumulative DD16			
Year	0-50 DAP	50-100 DAP	100-150 DAP	0 DAP-Har-vest
DP 20 1991	+0.007	+0.005	-0.004	-0.019
DP L50 1991	+0.017	+0.012	-0.010	-0.052
DP 90 1991	+0.012	+0.009	-0.007	-0.035
DP 5690 1991	+0.004	+0.001	-0.002	-0.019
DP 20 1992	+0.012	+0.010	-0.008	-0.043
DP 50 1992	+0.006	+0.004	-0.003	-0.017
DP 90 1992	+0.012	+0.010	-0.008	-0.041
DP 5690 1992	+0.005	+0.004	-0.003	-0.018

Table 11. Comparison of fiber maturation rates, based on A[n], of four cotton genotypes in 1991 and 1992.

Geno-type	Maturation rate [slope of A[n] vs. DD16] Cumulative DD16			
Year	0-50 DAP	50-100 DAP	100-150 DAP	0 DAP-Harvest
DP 20 1991	-0.061	-0.049	+0.038	+0.165
DP 50 1991	-0.052	-0.034	+0.029	+0.167
DP 90 1991	-0.028	-0.017	+0.015	+0.094
DP 5690 1991	-0.021	-0.011	+0.011	+0.075
DP 20 1992	-0.015	-0.018	+0.013	+0.078
DP 50 1992	-0.016	-0.016	+0.008	+0.035
DP 90 1992	-0.024	-0.0187	+0.015	+0.080
DP 5690 1992	-0.004	-0.0027	+0.002	+0.011

Table 12. Significant effects of genotype and environment on fiber spinning and dye-uptake properties. [Genotype X Year 2-way ANOVA]

	Mean Square and Significance Level		
	Genotype	Year	Genotype X Year
Yarn Property			
Nep Count	ns	1528.01 ***	ns
Uniformity CV%	ns	29.32 *	ns
Breaking Force	27421.99 ****	ns	ns
Breaking Tenacity	40.92 ****	ns	ns
Elongation Percent	7.44 ****	6.33 ****	ns
Dye-uptake [knit fabric tests]			
Total Color Difference [front]	ns	109.37 ****	ns
Total Color Difference [back]	ns	49.27 ****	ns
Chromaticity Difference [front]	ns	51.07 ****	ns
Chromaticity Difference [back]	ns	67.86 ****	ns

ns = p > 0.1; *, **, ***, **** indicate p < 0.1, 0.05, 0.01, and 0.001 respectively.